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Measuring Tidal Channel Turbulence with a Vertical Microstructure Profiler (VMP)

Detecting and Using Overturns

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1 Background

Turbulent eddies in a tidal channel will overturn the water column and temporarily reverse its vertical stratification of density. The length scale of overturning eddies, l, is related to the rate of dissipation of kinetic energy, ϵ, and the root-mean-square velocity fluctuations, q, by

$$q^3 = \epsilon l, \tag{1}$$

where

$$q^2 = \overline{u'^2} + \overline{v'^2} + \overline{w'^2}, \tag{2}$$

and u', v', and w' are the velocity fluctuations in the down-stream, cross-stream and vertical directions, respectively. Because the density stratification in a tidal channel is usually weak, the turbulent velocity fluctuations are nearly isotropic (independent of direction) which means that the variance of individual components are equal,

$$\overline{u'^2} = \overline{v'^2} = \overline{w'^2}, \tag{3}$$

and that the variance of the total fluctuating velocity (2) can be derived from any single component. Some anisotropy must occur, at the largest scales of the turbulence, in order to generate friction but it is unlikely that the variance of any one component will exceed that of another component by more than a factor of 2.

The overturning scale is revealed in a vertical profile by reversals in density. For the data collected in Islay Sound we measured only temperature (and not also salinity) and we will use the temperature profiles as a surrogate for density profiles. The temperature profile measured by the two fast sensors on the VMP profiler (Figure 1, left panel) shows numerous inversions including a large one between depth of 8 and 40 dbar[1]. Before this water entered the channel it was stably stratified and would have had a temperature profile that decreases monotonically from surface to bottom. If we resort the measured profile into one that is monotonic and keep track of the vertical displacement of each data point – the displacement required to make the profile monotonic – then we have a measure of the vertical scales of the turbulent eddies (Figure 1, middle panel). The displacement data (D_1 and D_2) have been smoothed by a running average of 0.2 m length. Water located between depths of 8 and 25 dbar, was moved up by as much as 22 dbar while water between 25 and 40 dbar was moved downward by this very large overturning eddy. Smaller eddies are visible below the large one, with the deepest eddy located 49 and 54 dbar. This deep eddy has vertical excursions of approximately 3 m.

If we apply (1) to the large eddy, then

$$(u',\ v') = \frac{1}{\sqrt{3}}\sqrt[3]{\epsilon l} = \frac{1}{\sqrt{3}}\sqrt[3]{5\times 10^{-6}\times 23} = 0.028\,\mathrm{m\,s^{-1}}. \tag{4}$$

where the factor of 1/3 is for the assumption of isotropy. This value should be considered an rms-estimate, and the peak-to-peak fluctuations are about 6 times larger, or $0.17\,\mathrm{m\,s^{-1}}$.

[1] A depth increase of 1 m is numerically almost identical to a pressure increase of 1 dbar, and we frequently use these two units interchangeably.

The vertical integration of the shear $\partial u'/\partial z$ and $\partial v'/\partial z$ (Figure 2), gives a value of $0.1\,\mathrm{m\,s^{-1}}$ peak-to-peak, and vertical integration of the shear underestimates (relatively speaking) the velocity fluctuations by a factor of 2. We expect this because the eddy size is much larger than the length of the profiler. The profiler is carried laterally by the eddy, in the direction of its large-scale velocity, and this reduces the *relative* velocity sensed by the shear probes.

If we apply (1) to the smaller bottom most eddy, then

$$(u',\ v') = \frac{1}{\sqrt{3}}\sqrt[3]{\epsilon l} = \frac{1}{\sqrt{3}}\sqrt[3]{5\times 10^{-5}\times 3} = 0.031\,\mathrm{m\,s^{-1}}. \tag{5}$$

The peak-to-peak velocity fluctuation is $0.18\,\mathrm{m\,s^{-1}}$ and vertical integration of the shear ($0.4\,\mathrm{m\,s^{-1}}$ peak-to-peak) overestimates (relatively speaking) the velocity fluctuations derived from the eddy scale. This is not expected because the size of the eddy is comparable to the length of the vertical profiler, and the instrument should not be strongly displaced by the eddy. However, the profiler tilts considerably, while it transits through this smaller eddy, and the measured shear has not been corrected for tilting. This is something that must be done but time has not yet allowed this calculation.

In addition, implicit in scaling laws of turbulence, which are mostly derived from dimensional analysis, is a non-dimensional factor of order unity. For example, (1) should read $q^3 = A\epsilon l$ where $A = O(1)$. Only observations can provide the numerical value of A. However, even assuming that $A = 1$ gives velocity estimates that are consistent within a factor of 2.

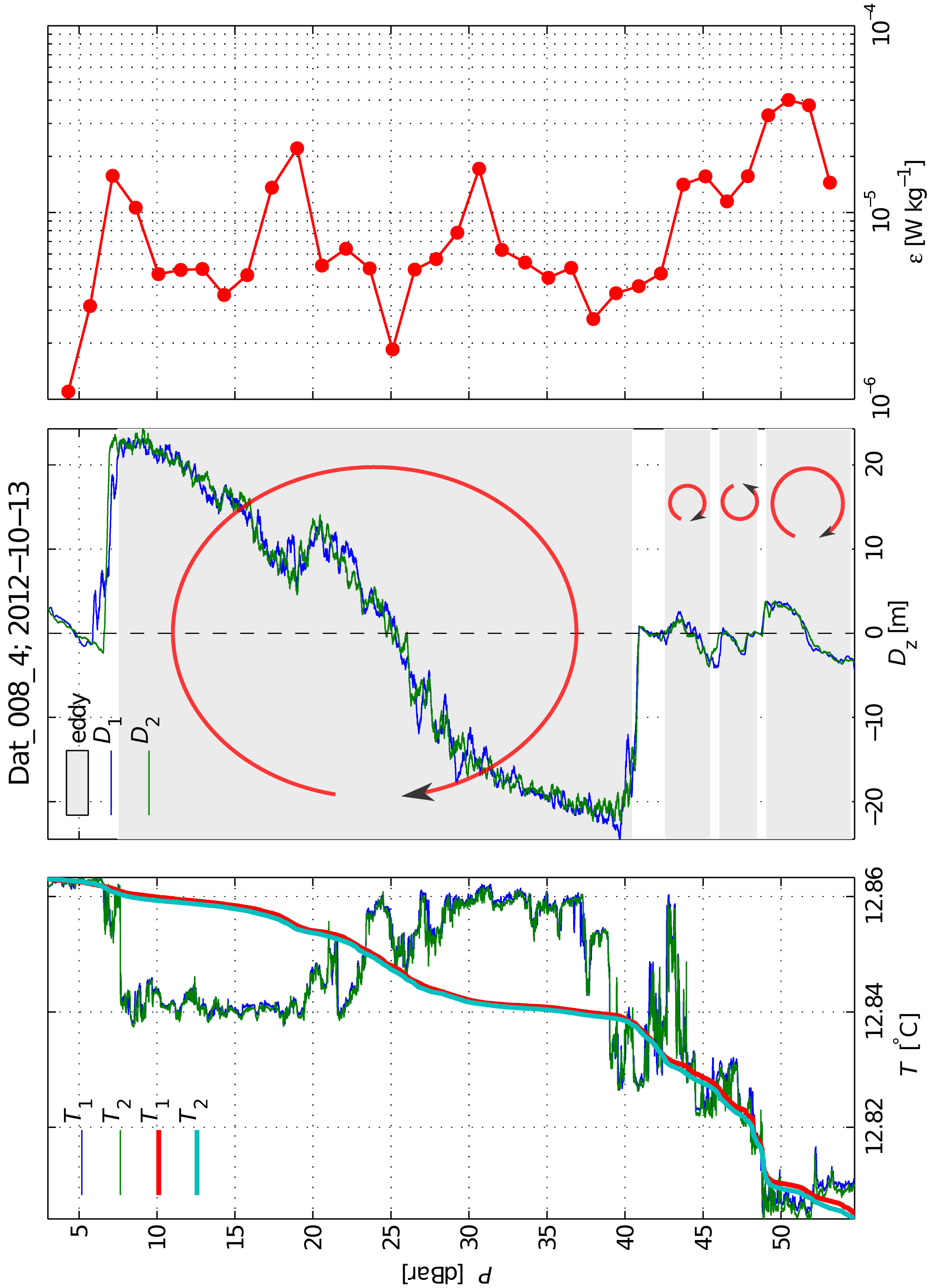

Figure 1: Temperature and dissipation rate profile in Islay Sound. Left panel – the *in situ* temperature (thin blue and green lines), and the same profile resorted to make its temperature decrease monotonically from top to bottom (thick red and cyan lines). Middle panel – the vertical distance that individual points in the original profile are moved vertically to create the monotonic profile. Right panel – the rate of dissipation of kinetic energy.

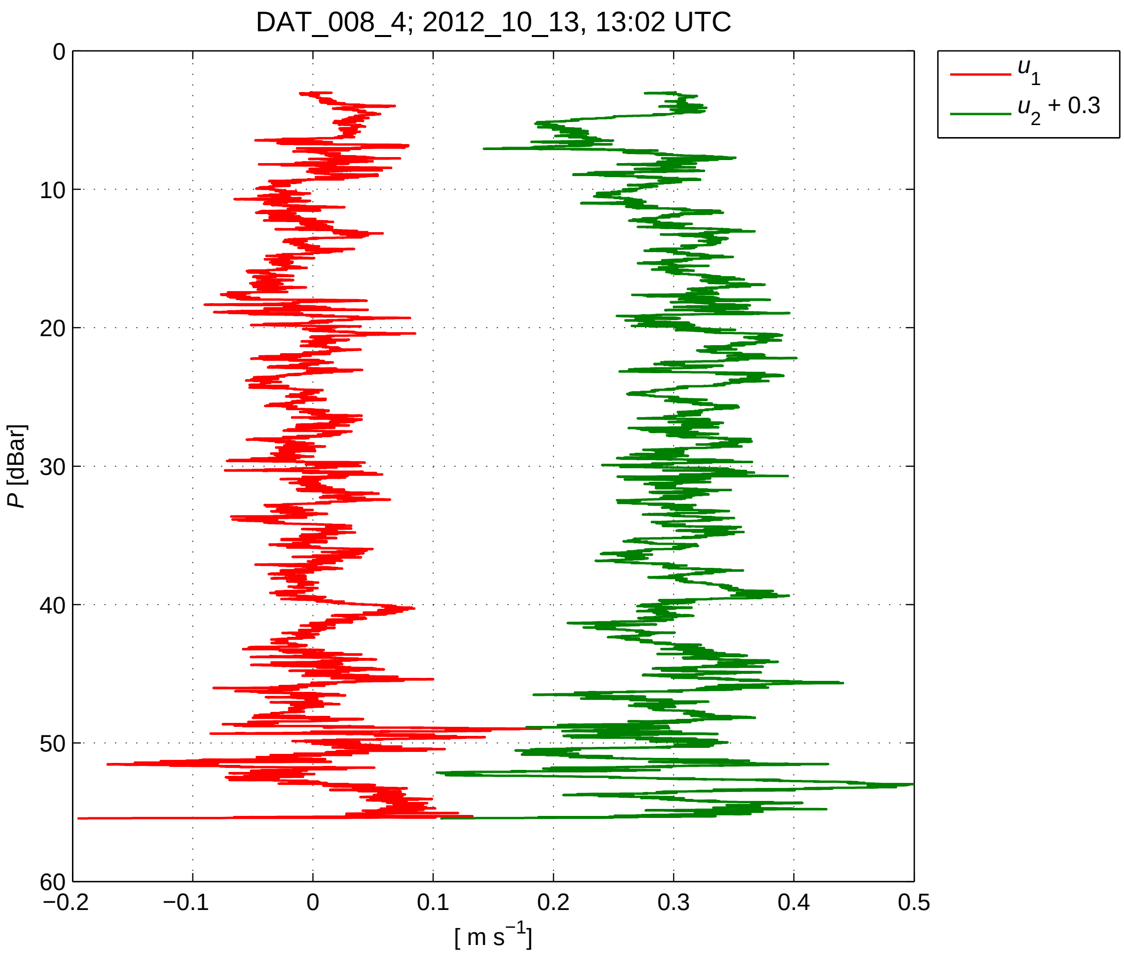

Figure 2: Velocity profiles in Islay Sound deduced by the vertical integration of the shear $\partial u'/\partial z$ and $\partial v'/\partial z$. Red trace – u' and green trace – v', off set by $0.3\,\mathrm{m\,s^{-1}}$ for clarity.

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